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Shorebird use of the Port of Brisbane, Queensland: insights from 30 years of monitoring

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For over 30 years, Port of Brisbane (Port) lands on Fisherman Island have been used as high tide roosting habitat by large numbers of shorebirds. Since January 2003, the Queensland Wader Study Group has been commissioned by Port of Brisbane Pty Ltd to undertake regular (typically monthly) counts of birds at roost sites on Fisherman Island. This paper reviews the long-term monitoring data to examine the importance of the Port roost sites to shorebirds in the adjoining Moreton Bay Ramsar site and assess seasonal and long-term variation in shorebird abundance. The annual average total migratory shorebird count on Fisherman Island over the period 2002 to 2023 was 7,110±917 (range 5,436 to 8,607) during the summer (non-breeding) period and 1,299±570 (528 to 2,820) during the winter (breeding) period. The annual average total resident shorebird count was 457±123 (277 to 797). Trends in the summer counts over the past 21 years were significantly negative for three species (Far Eastern Curlew, Grey Plover and Red-necked Stint) and significantly positive for three species (Bar-tailed Godwit, Great Knot and Broad-billed Sandpiper). Fisherman Island regularly supported around 20% and up to 39% of migratory shorebirds in Moreton Bay, including nationally significant numbers (greater than 0.1% of the East Asian-Australasian Flyway population) of 16 migratory shorebird species and internationally significant numbers (greater than 1% of the EAAF population) of six of these since 2002. Dredge reclamation ponds consistently supported 79-94% of the migratory shorebirds roosting at the Port, highlighting the important role that artificially created sites can play in shorebird conservation.

KEY WORDS: Conservation, East Asian–Australasian Flyway, Moreton Bay, artificial roost

INTRODUCTION

Located on the southern side of the mouth of the Brisbane River in Moreton Bay, the large commercial Port of Brisbane (the Port) in south-east Queensland on the central east coast of Australia is one of Australia's fastest growing container ports and Queensland's largest multi-cargo port. Prior to 1960, the site comprised a collection of islands surrounded by tidal mudflats (Fig. 1). The islands included several mangrove islands in the south, collectively known as the Fisherman Islands, together with Bishop Island in the north. Bishop Island was formed over the period 1909-1912 when the dredger 'Hercules' deposited 4.5 million tons of dredge material to the tidal flat on the southern side of the Brisbane River mouth (Ludlow 2013).

Brisbane River has a large sediment load, primarily due to gully and waterway channel erosion across its catchment (Wallbrink 2004, Olley *et al*. 2006, Lockington *et al.* 2017, Grinham *et al*. 2018, 2024). Large volumes of sediment are deposited into Moreton Bay, especially during floods (Steven *et al.* 2014, Grinham *et al*. 2024). This sediment causes siltation of shipping channels, necessitating regular dredging to remove the sediment to maintain safe navigable passage. The Port beneficially reuses the sediment to create port land, in turn creating temporary and permanent shorebird habitat. Construction of the current Port infrastructure footprint commenced in the early 1960s when dredge material was placed over the tidal mudflats to connect the Fisherman Islands into a single land mass, connected to the Lytton mainland through the construction of a road and rail bridge. Infilling with dredge material has taken place since then to expand Port infrastructure over tidal areas, Bishop Island and subtidal waters to the north and east to progressively develop the footprint to its current 770 ha extent (Fig. 1). The reclamation area was expanded considerably during 2004 with the construction of an outer bund rock wall enclosing a future port expansion area. Between 2004 and 2022, 10 to 20 ha cells within this expansion area have been progressively bunded off and used to settle dredge material and manage tailwater turbidity, a process that has resulted in the progressive infilling of these cells and their eventual incorporation into the expanded Port development.

The tidal flats to the north and south of the Brisbane River mouth provide important feeding habitat for shorebirds, particularly migratory shorebirds, used by several thousands of shorebirds when the flats become exposed at low tide (Thompson 1990, Driscoll 1993, Lloyd *et al*. 2021). While the construction of the Port has led to the loss of some areas of tidal flat feeding habitat, the dredge reclamation cells have provided ideal roosting habitat conditions for shorebirds over decades. These include (1) large areas of bare, open ground with little to no cover that provide a clear view of approaching

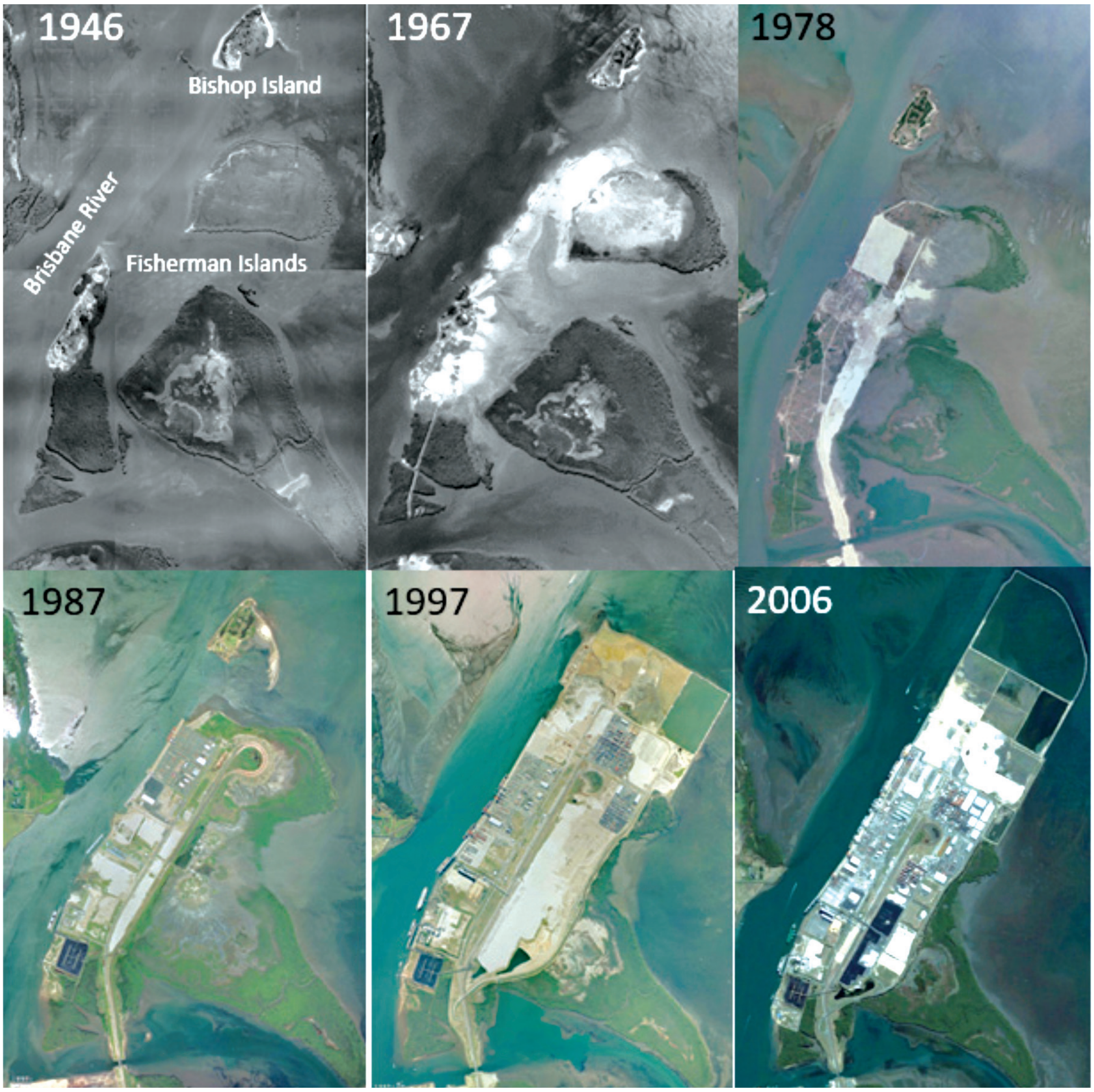

Figure 1. *Composite illustration of the development of the Port of Brisbane site between 1946 and 2006. Includes material © State of Queensland 2023 and © 2023 Google.*

predators; (2) being adjacent to the shoreline or incorporating areas of water and wet substrates that allow the birds to stay cool on hot days; (3) incorporating areas with uneven relief with small surface mounds and depressions that assist with camouflage and afford some protection from strong winds; (4) being close to preferred tidal flat feeding areas that reduces their energy expenditure flying between roosting and feeding sites (Rogers *et al.* 2006, Ryeland *et al.* 2021); and (5) periodic refreshment with a nutrient rich slurry from the dredge material that promotes the development of invertebrate communities in the shallow waters, providing food for smaller shorebirds such as Red-necked Stint and sandpipers, allowing them to continue feeding through the high-tide phase of the tidal cycle (Fuller *et al*. 2021). Additionally, the Port has also voluntarily created two large bird habitats, a permanent artificial roost and a freshwater lake on what would otherwise be industrial land.

The Queensland Wader Study Group (QWSG) has monitored shorebirds and other waterbirds on Fisherman Island since August 1991 (Driscoll 1994), including through standardised monthly counts since January 2003. At the same time, QWSG members have also regularly counted between 50 and 65 other high tide roosts in Moreton Bay to monitor shorebird numbers throughout Moreton Bay more broadly (Fuller *et al.* 2021). Moreton Bay is a Ramsar wetland of international significance and is the most important site for shorebirds in Queensland. Up to 37,900 shorebirds, including up to 35,800 migratory shorebirds, have been counted in Moreton Bay (Clemens *et al*. 2008), with a total estimate of up to 50,000 migratory shorebirds using Moreton Bay in the past (Thompson 1990). Moreton Bay regularly supports internationally significant numbers (greater than 1% of the East Asian-Australasian Flyway population) of nine migratory shorebird species (Fuller *et al*. 2021).

In this paper we review this long-term monitoring dataset to analyse trends in shorebird use of the roosts on Fisherman Island at the Port over the past 30 years, assess the relative importance of the Port for supporting roosting shorebirds in Moreton Bay and compare the results with short-term studies that have used alternative methods.

METHODS

QWSG high tide survey approach

Monitoring of shorebirds at the Port of Brisbane commenced in August 1991 and between three and 16 counts of all shorebirds found present on Fisherman Island within the period two hours either side of high tide were conducted annually to 2002 in an unstandardised way. From January 2003 a more standardised approach was implemented that aimed to conduct a high tide count at monthly intervals through each year. QWSG count volunteers generally met on site 1.5 hours before high tide to be briefed and assigned to one or more count sites in teams of at least two members, each team including at least one observer experienced in shorebird identification and counting. Each team then proceeded to record the total number of individuals for each species observed within their assigned sites within a 2-hour period, approximately an hour either side of high tide. Birds were observed through high-powered spotting telescopes mounted on sturdy tripods. Any movement of birds between count sites during the count was noted and communicated between teams to avoid double-counting. The standardised counts simultaneously surveyed all cells within the reclamation area, a purpose-built shorebird artificial roost site (PBAR), a nearby intertidal claypan (FICP), a permanent, 5 ha constructed freshwater lake (FIVC) and an ephemeral freshwater pond within a rail loop (PBRL) on Fisherman Island (Fig. 2). Counts prior to January 2003 were restricted to the reclamation area and claypan on Fisherman Island. Inclusion of the artificial roost and freshwater lake in the simultaneous monthly Port count schedule commenced in January 2003, and inclusion of the rail loop commenced in January 2014. A second claypan on Port lands on the mainland, Lytton Claypan No. 1 (LYN1, Fig. 2), has been included in the QWSG long-term monthly roost count programme, but counting of this site at the same time as the sites on Fisherman Island only commenced recently. Consequently, the LYN1 site was not included in the seasonal and trend analyses.

Figure 2. *Locations of shorebird count sites on Fisherman Island at Port of Brisbane, including the reclamation area, a purpose-built shorebird roost site (PBAR), a nearby intertidal claypan (FICP), a permanent freshwater lake (FIVC) and an ephemeral freshwater pondage area within a rail loop (PBRL). Also showing the Lytton Claypan No. 1 (LYN1) and Luggage Point (LUPO) roost sites on the mainland. Includes material © 2023 Google, © 2023 Airbus.*

Analyses

To examine seasonal variation in the total abundance of migratory and resident shorebirds, counts were assigned to approximately fortnightly intervals through the year (24 intervals) based on the count date. This examination showed that the total abundance of migratory shorebirds was relatively stable over the period 1 October to 15 March (summer, non-breeding season) and 1 May to 31 August (winter, breeding season), outside the peak periods of northward and southward migration. To examine long-term trends among migratory shorebirds, relevant surveys were attributed to one of the above two seasonal periods (winter: Double-banded Plover; summer: all other migratory species) or were otherwise excluded from analysis. To examine long-term trends among resident shorebirds, surveys in all months of the year were included. For these analyses, each year was treated as the period from 1 September to 31 August.

Temporal trends in the counts of individual species over the 21-year period of shorebird years 2002 to 2022 were tested using a generalised linear model (GLM). A quasi-Poisson model was used for each GLM since the count data were over-dispersed i.e. the variance was greater than the mean. Most of the roost sites at the Port are not influenced by the tide; consequently, the Port is thought to be a particularly important roost site for shorebirds on the highest spring high tides when many alternative roost sites in Moreton Bay become unsuitable for roosting due to tidal inundation. Each starting model for migratory shorebird species tested for a linear temporal trend, with counts as the dependent variable, year as the independent variable and tide height as a covariate. Each GLM for resident shorebirds tested for a linear temporal trend in counts, with counts as the dependent variable and year as the independent variable; tide height was not included as a covariate due to the reduction in overall tide heights in winter compared to in summer.

Models were fitted in R (R Core Team 2024) following the methods of Crawley (2015). Model simplification using backward elimination was adopted. Terms were systematically removed from the model and only retained if their removal resulted in a significant loss of model explanatory power, yielding a minimal model. The P-value for eliminated terms was determined by adding each individually to the minimal model. Averages are presented ±1 standard deviation (SD).

Table 1

Summary of migratory and resident shorebird species recorded on Fisherman Island at the Port of Brisbane over the shorebird years 2002 to 2022, their average (±1SD) summer (1 October to 15 March, migratory species) and winter (1 May to 31 August, migratory species) or annual (resident species) counts (with percentage of counts the species was present in parentheses), average annual maximum counts (with overall maximum count in parentheses), and index of relative importance (IRI). Values that exceed 0.1% of the EAAF population of the species are highlighted in bold and values that exceed 1% of the EAAF population are underlined.

Common name	Species	Summer (n=111)	Winter (n=83)	Annual maximum (max. count)	IRI
Migratory shorebirds					
Curlew Sandpiper	*Calidris ferruginea*	**1216**±717 (100%)	**122**±149 (99%)	**2026**±519 (**3408**)	83%
Lesser Sand Plover	*Charadrius mongolus*	**843**±496 (100%)	48±67 (78%)	**1418**±492 (**2433**)	73%
Greater Sand Plover	*Charadrius leschenaultii*	95±108 (94%)	6±19 (39%)	**240**±119 (**441**)	72%
Red-necked Stint	*Calidris ruficollis*	**2288**±1262 (100%)	**650**±558 (100%)	**3833**±1397 (**6803**)	71%
Pacific Golden Plover	*Pluvialis fulva*	**370**±211 (100%)	14±18 (65%)	**580**±266 (**1219**)	70%
Ruddy Turnstone	*Arenaria interpres*	**69**±56 (98%)	19±29 (69%)	**131**±60 (**248**)	62%
Sharp-tailed Sandpiper	*Calidris acuminata*	**448**±389 (100%)	30±171 (61%)	**922**±535 (**2078**)	59%
Grey-tailed Tattler	*Tringa brevipes*	**591**±316 (97%)	**129**±171 (74%)	**1018**±264 (**1434**)	42%
Grey Plover	*Pluvialis squatarola*	28±20 (93%)	2±3 (27%)	48±24 (**145**)	41%
Great Knot	*Calidris tenuirostris*	186±164 (97%)	8±29 (35%)	379±190 (**708**)	26%
Red Knot	*Calidris canutus*	35±114 (57%)	2±7 (11%)	**236**±221 (**760**)	24%
Broad-billed Sandpiper	*Calidris falcinellus*	7±16 (59%)	<1±1 (6%)	29±38 (**131**)	22%
Double-banded Plover	*Charadrius bicinctus*	<1±<1 (7%)	**24**±22 (93%)	**46**±37 (**172**)	19%
Eurasian Whimbrel	*Numenius phaeopus*	41±53 (91%)	9±38 (49%)	**146**±97 (**405**)	11%
Bar-tailed Godwit	*Limosa lapponica baueri*	**729**±408 (99%)	210±198 (89%)	**1088**±386 (**1633**)	9%
Far Eastern Curlew	*Numenius madagascariensis*	**131**±83 (97%)	**43**±60 (77%)	**247**±72 (**340**)	7%
Common Greenshank	*Tringa nebularia*	4±5 (78%)	1±3 (26%)	11±8 (37)	6%
Marsh Sandpiper	*Tringa stagnatilis*	1±3 (36%)	<1±<1 (6%)	5±5 (18)	2%
Terek Sandpiper	*Xenus cinereus*	3±6 (60%)	1±4 (25%)	11±11 (42)	2%
Black-tailed Godwit	*Limosa limosa*	1±5 (20%)	<1±1 (10%)	6±12 (54)	1%
Sanderling	*Calidris alba*	<1±1 (4%)	<1±<1 (1%)	<1±2 (8)	
Wandering Tattler	*Tringa incana*	<1±<1 (13%)	<1±<1 (1%)	<1±<1 (3)	
Asian Dowitcher	*Limnodromus semipalmatus*	<1±<1 (5%)	0	<1±<1 (1)	
Buff-breasted Sandpiper	*Calidris subruficollis*	<1±<1 (2%)	0	<1±<1 (1)	
Common Sandpiper	*Actitis hypoleucos*	<1±<1 (3%)	0	<1±<1 (1)	
Latham's Snipe	*Gallinago hardwickii*	<1±<1 (5%)	0	<1±<1 (1)	
Ruff	*Calidris pugnax*	0	0	<1±<1 (1)	
Total migratory		**7110±917**	**1299±570**	**9473±1967 (13703)**	
Resident shorebirds					
Black-fronted Dotterel	*Elseyornis melanops*	1±2 (41%)		4±3 (13)	
Bush Stone-curlew	*Burhinus grallarius*	<1±<1 (1%)			
Masked Lapwing	*Vanellus miles*	5±3 (89%)		10±3 (14)	
Pied Oystercatcher	*Haematopus longirostris*	70±52 (99%)		160±47 (240)	
Pied Stilt	*Himantopus leucocephalus*	152±130 (97%)		386±186 (1070)	
Red-capped Plover	*Charadrius ruficapillus*	76±50 (100%)		155±60 (279)	
Red-kneed Dotterel	*Erythrogonys cinctus*	1±6 (14%)		6±15 (53)	
Red-necked Avocet	*Recurvirostra novaehollandiae*	151±271 (76%)		543±596 (2810)	
Sooty Oystercatcher	*Haematopus fuliginosus*	<1±1 (12%)		1±2 (6)	
Total resident		**457±123**		**981±566 (3126)**	

To assess the relative importance of the roosts on Fisherman Island to migratory shorebird species in Moreton Bay, an index of relative importance (IRI) was calculated for each species as the ratio of the average annual maximum count at the Port over the period 2003 to 2023 to the maximum count for Moreton Bay since 2008 as reported in Fuller *et al*. (2021), expressed as a percentage:

$$IRI = \frac{\text{Average Annual Maximum Count}}{\text{Maximum count for Moreton Bay since 2008}} \times 100$$

The significance of the roosts on Fisherman Island collectively and individually was also assessed on the basis of the percentage of the East Asian-Australasian Flyway (EAAF) population (Hansen *et al.* 2016) that the respective species counts represent, where counts representing greater than 1% of the EAAF population are internationally significant (Ramsar 1971, Clemens *et al*. 2010) and counts representing greater than 0.1% of the EAAF population are nationally significant (Clemens *et al.* 2010).

Scientific names are given in Table 1.

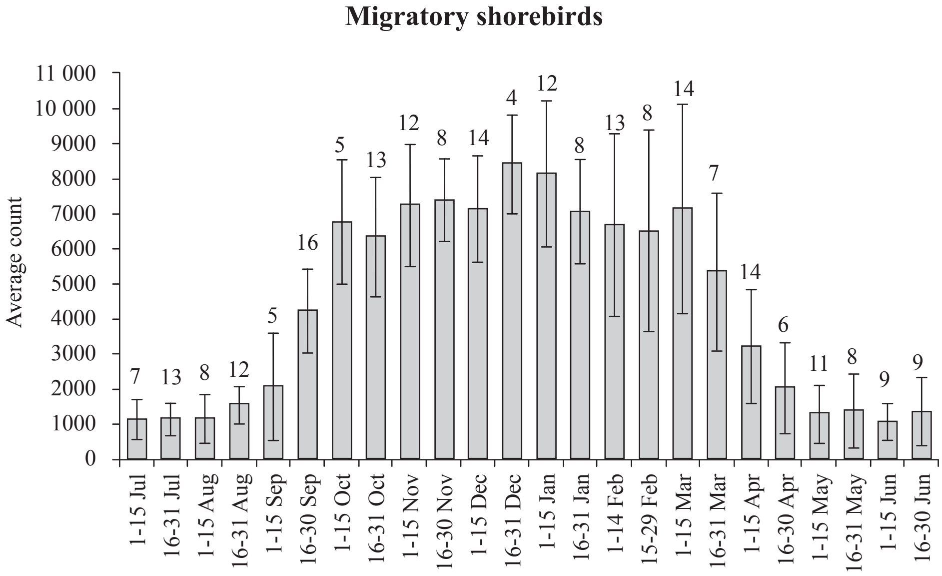

Figure 3. *Average (±1 SD) total migratory shorebird counts on Fisherman Island each fortnight through the year over the shorebird years 2002-2022. The total number of counts for each fortnight is shown above the respective column.*

RESULTS

Species composition and site importance

A total of 27 migratory shorebird species and nine resident shorebird species have been recorded on Fisherman Island since January 2003 (Table 1). Resident shorebirds were substantially less abundant than migratory shorebirds, making up only 9% of the overall total shorebird abundance from all counts since 2003. The annual average total migratory shorebird count on Fisherman Island since 2003 was 7,110±917 (range 5,436-8,607) during the summer (non-breeding) period and 1,299±570 (range 528-2,820) during the winter (breeding) period. The annual maximum total migratory shorebird count since 2003 averaged 9,473±1,967 (range 7,159-13,703). The annual average total resident shorebird count since 2003 was 457±123 (range 277-797) and the annual maximum count averaged 981±566 (range 495-3,126).

The index of relative importance of the roosts on Fisherman Island to migratory shorebird species ranged between 87% for Curlew Sandpiper and <1% for Black-tailed Godwit and Sanderling (Table 1). Thus, the average annual maximum count of Curlew Sandpiper on Fisherman Island was 87% of the all-time maximum count of Curlew Sandpiper reported by Fuller *et al*. (2021) for the whole of Moreton Bay since 2008. The index of relative importance of Fisherman Island was greater than 50% for seven species and greater than 20% for 12 species (Table 1). The roosts on Fisherman Island have together supported nationally significant numbers (greater than 0.1% of the EAAF population) of 16 migratory shorebird species and internationally significant numbers (greater than 1% of the EAAF population) of six of these since 2002 (Table 1).

The reclamation area ponds consistently supported 79-94% of the migratory shorebirds and 47-85% of resident shorebirds each year since 2003. Averaged across all years, the reclamation area ponds supported 88%, the Fisherman Island claypan 8%, the artificial roost 4%, and the freshwater lake and rail loop less than 1% of the migratory shorebirds. Averaged across all years, the reclamation area ponds supported 70%, the artificial roost 17%, the Fisherman Island claypan 10%, the freshwater lake 3% and rail loop less than 1% of the resident shorebirds. Species that were frequently observed foraging in the shallow waters or wet edges of the reclamation area ponds and regularly at the Fisherman Island claypan roost sites at high tide included Red-necked Stint, Curlew Sandpiper, Sharp-tailed Sandpiper, Broad-billed Sandpiper, Pied Stilt and Red-capped Plover. Lesser and Greater Sand Plovers foraged less frequently. Migratory shorebirds rarely visited the freshwater lake; small numbers of Curlew Sandpiper, Sharp-tailed Sandpiper, Red-necked Stint and Marsh Sandpiper were recorded only after the water levels at the lake had declined to very low levels during extended dry periods. The same species were rarely recorded at the rail loop, but in this case only after heavy rainfall had flooded a basin inside the rail loop. The rail loop basin is an artefact of stormwater drainage management that currently allows the basin to flood after heavy rainfall.

All four main roost sites at the Port, three on Fisherman Island together with the Lytton Claypan No. 1 on the mainland, have supported nationally significant (greater than 0.1% of the EAAF population) and two, the reclamation area and Lytton Claypan No. 1 have supported internationally significant numbers (greater than 1% of the EAAF population) of migratory shorebird species within the most recent five years (Table 2).

Seasonal variation in shorebird abundance

Total migratory shorebird numbers roosting on Fisherman Island exhibited the expected cyclical pattern of an influx during their non-breeding season followed by an exodus prior to the start of their breeding season (Fig. 3). Total migratory shorebird numbers were consistently high and most stable over the period October to mid-March. There was some variation in seasonal patterns of abundance between migratory shorebird species. Far Eastern Curlew had the earliest apparent arrival during the southward migration, with increased counts from the first half of August, and the earliest apparent departure

Table 2

Summary of migratory and resident shorebird species recorded at the four main roost sites at the Port of Brisbane over the past five years since September 2018, their average (±1SD) summer (1 October to 15 March, migratory species except Double-banded Plover), winter (1 May to 31 August, Double-banded Plover) or annual (resident species) counts, with overall maximum count in parentheses. Values that exceed 0.1% of the EAAF population of the species are highlighted in bold and values that exceed 1% of the EAAF population are underlined.

Common name	Reclamation Area (n=28)	Artificial Roost (n=28)	Fisherman Isl. Claypan (n=28)	Lytton Claypan No. 1 (n=45)
Migratory shorebirds				
Asian Dowitcher	<0.1±0.2 (1)	0.1±0.3 (1)	0	0
Bar-tailed Godwit	**521**±414.2 (**1567**)	121.6±307.8 (**1318**)	45.1±114.1 (**402**)	**698.3**±563.7 (**3010**)
Black-tailed Godwit	0.1±0.3 (1)	0.3±0.5 (2)	0.1±0.6 (3)	6.7±15.9 (71)
Broad-billed Sandpiper	13.1±21.1 (76)	0.6±1.7 (8)	0.1±0.4 (2)	0
Buff-breasted Sandpiper	0	0.1±0.3 (1)	0	0
Common Greenshank	0.1±0.4 (2)	1.5±2 (6)	1.3±6.6 (35)	0.6±1.6 (8)
Common Sandpiper	<0.1±0.2 (1)	0	0	0
Curlew Sandpiper	**1322**±950.7 (**3408**)	20.1±40.8 (**166**)	41.7±82.5 (**289**)	**125.7**±267.9 (**1251**)
Double-banded Plover	**20.6**±10.7 (**37**)	0	0	0
Eurasian Whimbrel	0.1±0.6 (3)	9±14.7 (45)	26.3±38.2 (**157**)	**102.6**±69.8 (**210**)
Far Eastern Curlew	**65.1**±84 (**290**)	1.5±1.2 (4)	**59.3**±99 (**340**)	**198.7**±107 (**438**)
Great Knot	159.6±142.8 (**482**)	11.1±36.8 (185)	5.9±16.4 (71)	63.2±120.8 (**431**)
Greater Sand Plover	77.3±83.4 (**305**)	0	0	0
Grey Plover	24.5±14.1 (49)	0	0	0
Grey-tailed Tattler	**598.3**±392.9 (**1434**)	0.3±1.3 (7)	0	0
Lesser Sand Plover	**764.9**±479.5 (**2053**)	0	0	0
Marsh Sandpiper	0.6±1.4 (5)	<0.1±0.2 (1)	0.1±0.4 (2)	2.2±5.4 (22)
Pacific Golden Plover	**401.1**±244.7 (**1204**)	1.8±2.1 (6)	5.7±8.2 (26)	0.1±0.3 (2)
Red Knot	12.5±30.5 (**152**)	2.1±6.5 (31)	<0.1±0.2 (1)	3.9±8.2 (34)
Red-necked Stint	**1290.2**±701.3 (**2734**)	10.3±17.3 (60)	171±286.2 (**1350**)	43.5±72.8 (286)
Ruddy Turnstone	**73.1**±71.6 (**248**)	0	<0.1±0.2 (1)	0
Sanderling	0.1±0.3 (1)	0	0	0
Sharp-tailed Sandpiper	**417.4**±332.1 (**1640**)	25±25 (**113**)	60.1±143.5 (**637**)	66±126.7 (**505**)
Terek Sandpiper	0.6±1.5 (6)	0	0	0
Wandering Tattler	<0.1±0.2 (1)	0	0	0
Resident shorebirds				
Black-fronted Dotterel	0.4±1 (4)	0.6±0.9 (3)	0.4±1.3 (8)	1.1±2.8 (12)
Masked Lapwing	0.9±1.8 (10)	1.2±0.9 (3)	2.7±2.2 (9)	7.2±7.6 (29)
Pied Oystercatcher	79.1±66.3 (240)	1.3±1.1 (4)	0.9±2.1 (11)	6.6±21.6 (189)
Pied Stilt	21.8±36.1 (138)	50.1±62 (229)	76±167.9 (1070)	108.7±165.3 (922)
Red-capped Plover	79.6±49.2 (247)	1.2±1.6 (7)	7.2±8 (44)	6.1±10.1 (41)
Red-kneed Dotterel	0	0.1±0.4 (2)	0	0.4±3.6 (34)
Red-necked Avocet	77.2±162.9 (896)	1.5±5.1 (32)	1.9±14.4 (108)	13.4±39.1 (205)
Sooty Oystercatcher	0.5±1.2 (6)	0	0	0
Total migratory	*5743.5±2057.2 (9646)*	*205.3±379.7 (1607)*	*416.8±424.2 (1459)*	*1322.6±819.4 (3927)*
Total resident	*259.5±180 (1032)*	*56±64 (232)*	*89±174 (1086)*	*143.5±178.4 (944)*

during northward migration, with low counts from mid-March (Fig. 4). By contrast, species such as Bar-tailed Godwit, Great Knot, Red Knot, Pacific Golden Plover, Grey Plover and Red-necked Stint began increasing in numbers from mid-September, whereas Lesser and Greater Sand Plovers only began increasing from late September through the first half of October. Red Knot was most abundant within the period mid-September to mid-October. Double-banded Plover, which breeds in New Zealand during the austral summer and migrates to Australia for the non-breeding period through the austral winter (Pierce 1999), was generally present from the first half of April through to mid-August (Fig. 4).

The four most common resident shorebird species showed variable seasonal changes in abundance (Fig. 5). Counts of Red-capped Plover, which is a resident breeder at the site, remained relatively uniform throughout the year whereas counts of Pied Oystercatcher increased from January to March, suggesting an influx of birds at this time, before decreasing again (Fig. 5). Red-necked Avocet and Pied Stilt showed a seasonal pattern of increased abundance from mid-April before gradually declining to reach lowest abundance within the period October/November through to March, during the summer wet season.

Long-term trends in shorebird use of the Port

There was limited evidence that the abundance of migratory shorebirds using the Port for roosting increased with increasing

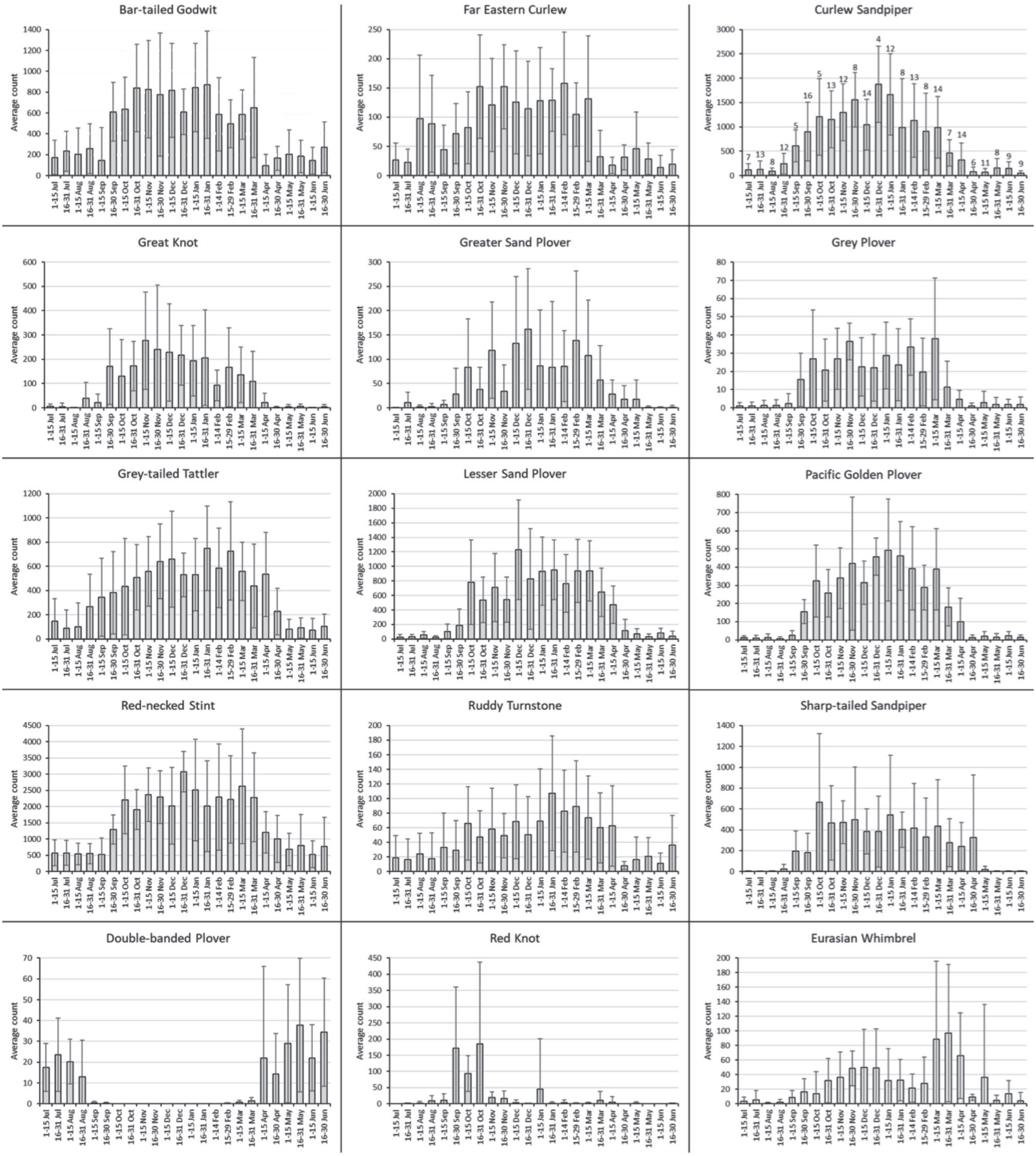

Figure 4. *Average (±1 SD) counts for individual migratory shorebird species on Fisherman Island each fortnight through the year over the shorebird years 2002-2022.*

high tide levels; a significant positive relationship between abundance and tide height was detected for only Red-necked Stint in summer (Table 3). Among migratory shorebird species, there was a significant decreasing trend in the average summer count for three species (Far Eastern Curlew, Grey Plover and Red-necked Stint) and a significant increasing trend for three species (Bar-tailed Godwit, Great Knot and Broad-billed Sandpiper) over the 21-year period 2002-2022 (Fig. 6). Broad-billed Sandpiper was infrequently recorded in low numbers prior to 2014, whereafter numbers have increased, particularly during the northward migration in March-April. Among resident shorebird species, there was no significant trend in the average annual count for the four commonly occurring species over the 21-year period 2002-2022 (Fig. 7).

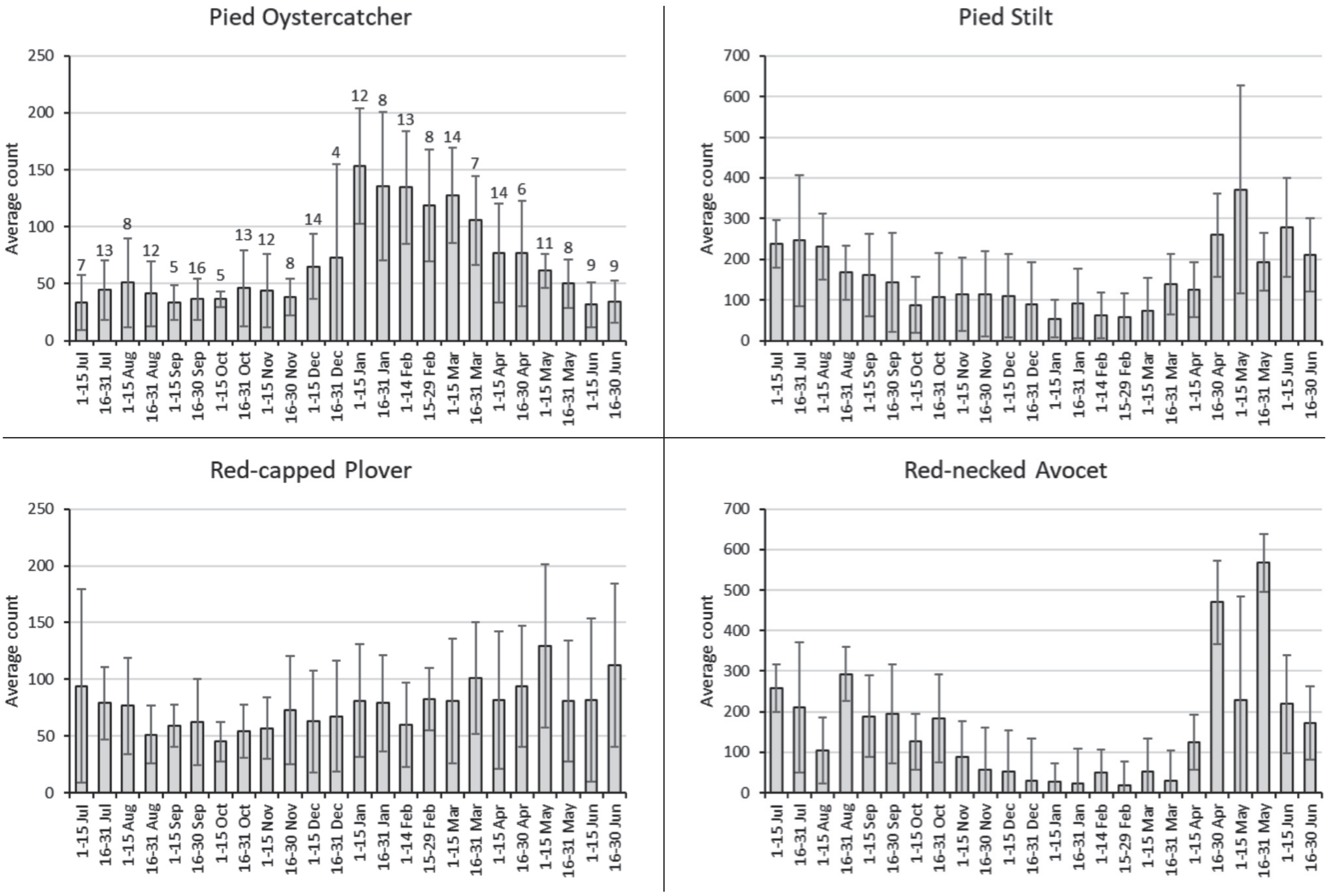

Figure 5. *Average (±1 SD) counts for individual resident shorebird species on Fisherman Island each fortnight through the year over the shorebird years 2002-2022.*

Table 3

Summary of results of generalised linear models (GLMs) run separately for each species to test for a linear temporal trend in roosting abundance and whether tide height influenced roosting abundance (migratory shorebirds only).

	Effect size ± SE			*F*		*P*	
Species	Intercept	Year	Tide	Year	Tide	Year	Tide
Broad-billed Sandpiper	-277.68±65.51	0.138±0.032	1.00±0.91	20.98	1.17	<0.001	0.28
Bar-tailed Godwit	-27.44±17.34	0.017±0.009	0.04±0.33	3.92	0.02	0.05	0.9
Curlew Sandpiper	-41.36±17.90	0.024±0.009	0.23±0.34	7	0.46	0.009	0.5
Double-banded Plover	33.68±36.67	-0.014±0.019	-0.97±0.84	2.19	2.94	0.14	0.09
Eurasian Whimbrel	36.02±40.40	-0.016±0.020	0.03±0.78	0.68	0.02	0.41	0.89
Far Eastern Curlew	54.07±20.14	-0.025±0.010	0.08±0.39	6.45	0.04	0.013	0.84
Great Knot	-69.35±26.96	0.037±0.013	0.14±0.50	7.73	0.08	0.006	0.78
Greater Sand Plover	43.31±36.03	-0.019±0.018	-0.60±0.68	0.9	0.52	0.35	0.47
Grey Plover	82.31±21.93	-0.040±0.011	0.38±0.43	14.69	0.74	<0.001	0.39
Grey-tailed Tattler	-15.20±16.69	0.011±0.008	0.20±0.32	1.46	0.21	0.23	0.65
Lesser Sand Plover	-9.92±18.72	0.008±0.009	0.08±0.36	0.75	0.01	0.39	0.91
Pacific Golden Plover	14.75±18.12	-0.005±0.009	0.16±0.35	0.33	0.28	0.57	0.6
Red-necked Stint	53.91±16.55	-0.024±0.008	0.71±0.33	8.52	4.68	0.004	0.033
Ruddy Turnstone	-27.32±25.31	0.015±0.013	0.20±0.48	1.43	0.07	0.23	0.8
Sharp-tailed Sandpiper	1.97±27.70	0.003±0.014	-0.46±0.52	0.09	0.85	0.76	0.36
Pied Oystercatcher	-21.27±15.77	0.013±0.008		2.62		0.11	
Pied Stilt	-8.80±18.30	0.007±0.009		0.57		0.45	
Red-capped Plover	-44.41±13.67	0.024±0.007		12.8		<0.001	
Red-necked Avocet	7.07±38.46	-0.001±0.019		0.01		0.96	

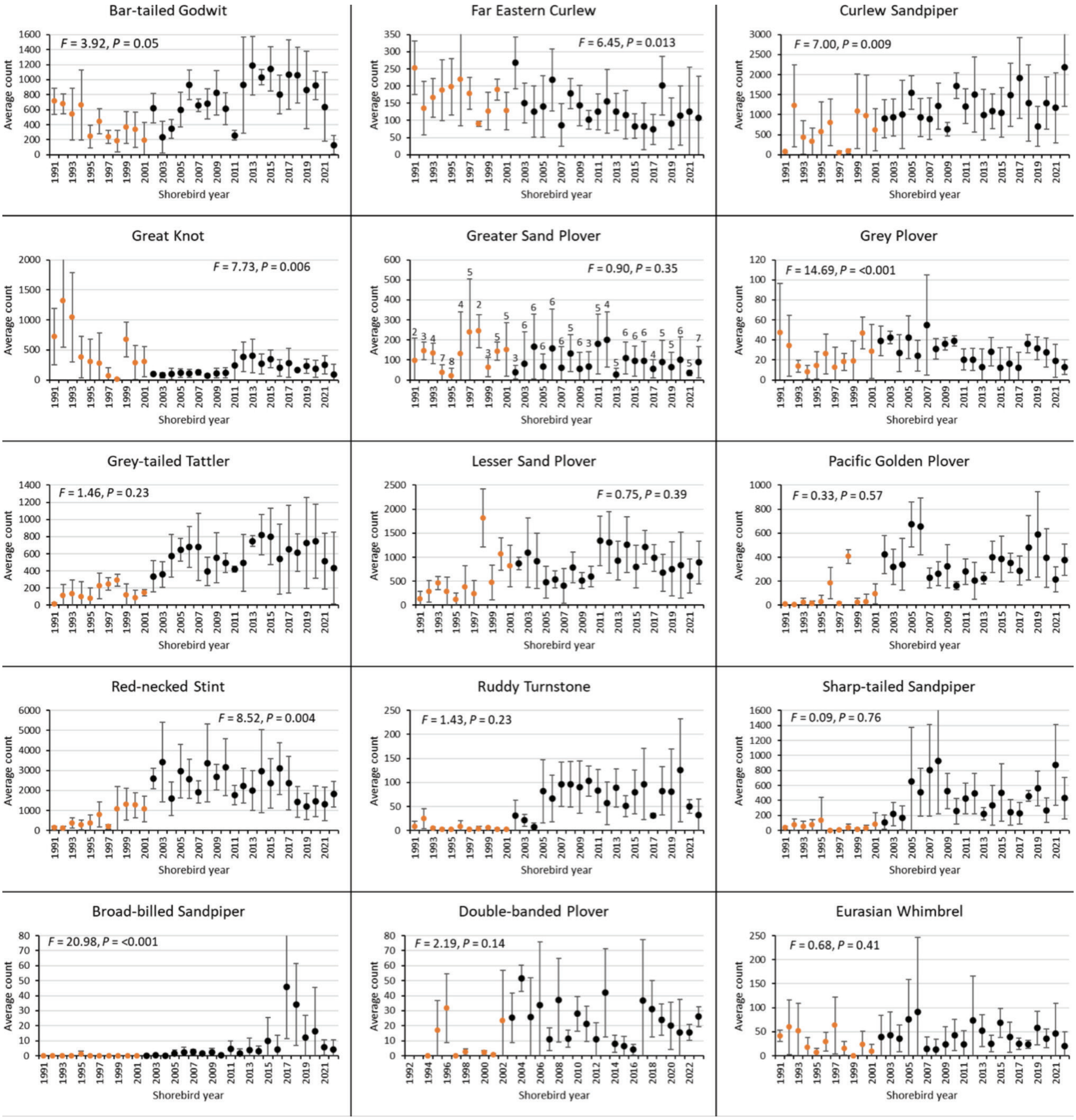

Figure 6. *Temporal trends in total Fisherman Island counts (±1 SD) for 15 migratory shorebird species during the summer period (1 October to 15 March: 14 species) or winter period (1 May to 31 August: Double-banded Plover).*

DISCUSSION

Site importance

The annual average total migratory shorebird count of 7,110 and the range in the annual maximum count of between 7,159 and 13,703 during the summer (non-breeding) period confirm that Fisherman Island at the Port of Brisbane is the most important roosting area for migratory shorebirds in Moreton Bay. Around 35,000 migratory shorebirds are reported to visit Moreton Bay during the non-breeding season (Fuller *et al*. 2021), suggesting that the roosts on Fisherman Island regularly support around 20% and up to 39% of migratory shorebirds in Moreton Bay. The importance of Fisherman Island as a roosting area is also confirmed by the index of relative importance calculations for individual species, which showed that the average annual maximum counts at Fisherman Island as a percentage of the all-time maximum counts reported by Fuller *et al*. (2021) for the whole of Moreton Bay since 2008 exceeded 50% for seven

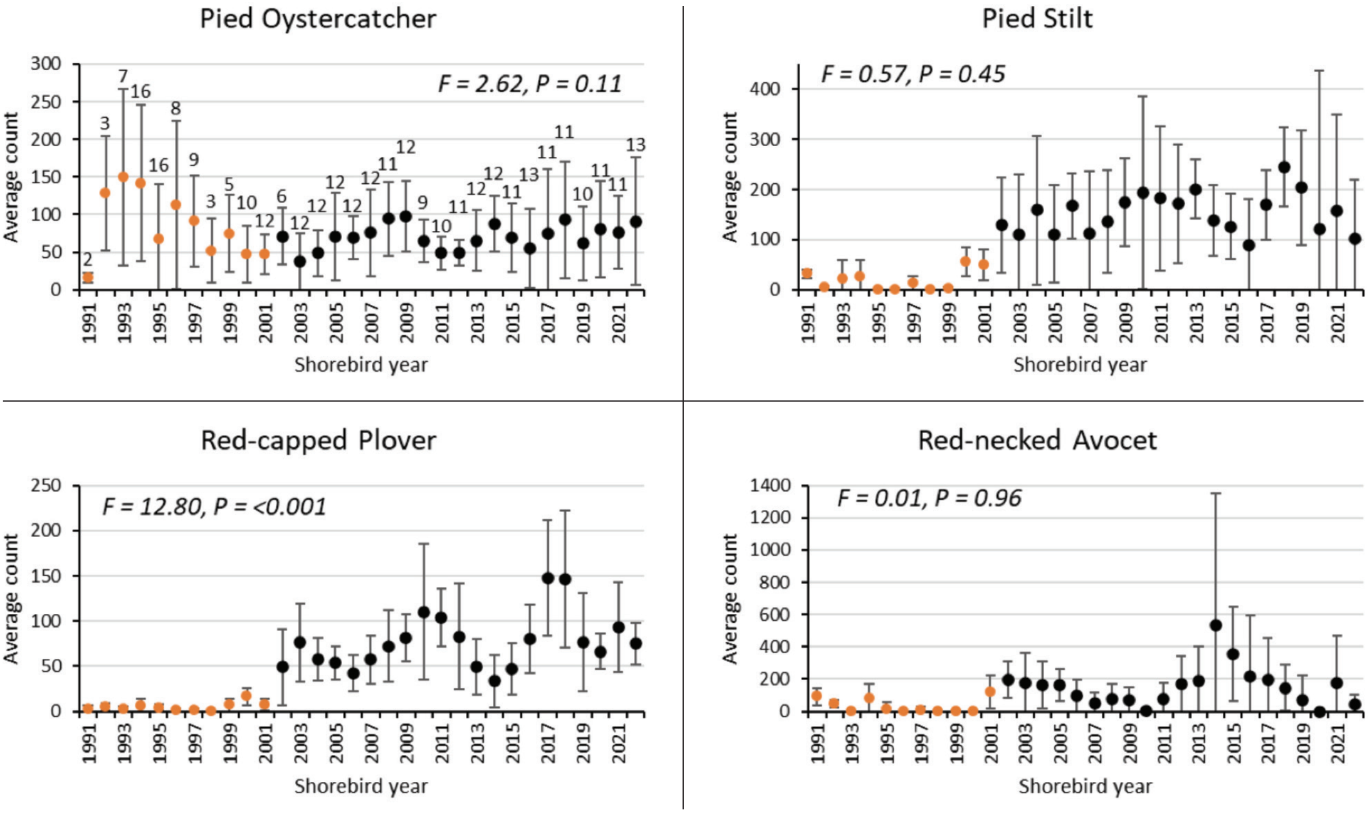

Figure 7. *Temporal trends in total Fisherman Island counts (±1 SD) for four resident shorebird species.*

species and exceeded 20% for 12 species (Table 1). Fisherman Island is a disproportionately important roosting area for Curlew Sandpiper in particular, with an index of relative importance of 87%. Maximum counts of 3,196 and 3,408 Curlew Sandpiper on Fisherman Island a week apart in January 2023 exceeded the whole-of-Moreton-Bay maximum count since 2008 of 2,443 (Fuller *et al*. 2021) by up to 40%. The ponds within the reclamation area at the Port are attractive as roost sites for smaller species including Curlew Sandpiper, Red-necked Stint, Sharp-tailed Sandpiper and Broad-billed Sandpiper since these birds can continue to feed on small invertebrates in the shallow, nutrient-rich water and soft, muddy substrates of these ponds. Artificial habitats supported most of the shorebirds using the Port, particularly the dredge reclamation ponds that consistently supported 79-94% of the migratory shorebirds. This result provides further evidence of the important role that artificial habitats can play in shorebird conservation (Dias *et al*. 2014, Jackson *et al.* 2020, 2021).

The tidal flats within a 15 km radius of the Port also support relatively high foraging densities at low tide of Curlew Sandpiper, Red-necked Stint, Pacific Golden Plover, Great Knot, Lesser Sand Plover and Sharp-tailed Sandpiper compared with other areas of Moreton Bay (Thompson 1990, Driscoll 1991, Lloyd *et al*. 2021, Fuller *et al.* 2021). Thus, proximity of the Port to preferred foraging habitats may also contribute to the preference of these species for roosting at the Port. Another contributing factor may be the limited disturbance of shorebirds on Fisherman Island; all the main shorebird roosts are fenced with no public access, and disturbance from operational activities occurs only occasionally, with birds able to move between the multiple suitable roost sites when they are disturbed.

The high variability of the summer season counts within each year, evidenced by the large standard deviations (Fig. 6), indicates that many of the shorebirds using roost sites on Fisherman Island are likely to also be using alternative roost sites outside Fisherman Island on a regular basis. The other important shorebird roost sites nearby include Lytton Claypan No. 1, Luggage Point and Manly Harbour. Satellite tracking and leg flag resighting have confirmed substantial movement of birds between the Port roosts and other roost sites (Coleman and Milton 2012, Coleman and Bush 2020, Lilleyman *et al*. 2020). Unlike roost sites elsewhere in Moreton Bay, most of the roost sites at the Port are not affected by the relative height of high tides. Thus, it was expected that some of the variability in species counts might be explained by increased numbers of birds using the Port on higher spring tides when alternative roost sites become unsuitable due to inundation; however, there was limited evidence that the abundance of migratory shorebirds using the Port for roosting increased with increasing high tide levels.

Seasonal variation in shorebird abundance

The patterns of seasonal change in the abundance of migratory shorebird species (Fig. 4) are broadly consistent with previously published information, with some exceptions. The increased abundance of Far Eastern Curlew from August through to the middle of March is broadly consistent with the findings of a study of ten satellite tracked birds over multiple years, which found that the arrival dates of birds migrating back from their breeding grounds ranged from mid-August to late November, with nearly all birds having departed again on their northward migration by mid-March (Morrick *et al*. 2022); however, the consistently high average numbers from the second half of October suggest either most birds have arrived by mid-October or some are pausing in Moreton Bay before continuing south. Similarly, the high average numbers in the first half of March, despite the satellite tracking showing most Far Eastern Curlew have departed by mid-March, suggests a possible influx of birds from the south during this period.

Great Knots have previously been described as arriving in Moreton Bay in early October (Higgins and Davies 1996); however, the pattern of increased numbers at the Port from the second half of September indicates some birds start arriving earlier (Fig. 4). Reduced numbers of Great Knot from February suggest departure on northward migration occurs from February, with most birds having departed by the end of March; however, Thompson (1993) recorded large numbers of Great Knot in eastern Moreton Bay as late as the first week of April in 1989. Numbers of Pacific Golden Plover increased from late September through to November (Fig. 4), suggesting an extended influx over this period, with departure on northward migration from the second half of March to early April. Yet, three Pacific Golden Plovers fitted with Platform Terminal Transmitters (PTTs) all departed Moreton Bay in the last week of April (Coleman and Bush 2020), suggesting later departure for some birds than the pattern of abundance at the Port would suggest.

Red Knots were most abundant within the period mid-September to mid-October, decreasing thereafter, suggesting they stop over in Moreton Bay during the southward migration before continuing to non-breeding grounds further south, and they do not stop over in Moreton Bay on the return northward migration. A similar pattern of movement of Red Knots has been recorded at the Hunter Estuary in NSW, where they moved through in waves in late September to early October, with most birds staying for less than a week before continuing to New Zealand, and no birds being recorded during the return northward migration (Crawford and Herbert 2017). Large numbers of Sharp-tailed Sandpiper are known to use inland freshwater wetlands when they are receding after flooding (Higgins and Davies 1996, Lloyd *et al*. 2020). Therefore, one might expect Sharp-tailed Sandpiper numbers visiting coastal wetlands to be variable depending on seasonally and annually variable conditions at inland wetlands. Specifically, one might expect numbers to be higher during the early non-breeding season (October-November) and lower later in the summer wet season once inland freshwater wetlands are more frequently flooded. Sharp-tailed Sandpiper counts were highly variable both between years and through the summer non-breeding season; however, the pattern of seasonal variation was not consistent with a predicted decrease in average numbers through the non-breeding season (Fig. 4). The peak abundance in March to mid-April also suggests that Moreton Bay may function as a stopover site for Eurasian Whimbrel on northward migration, the only species for which we found evidence of an influx during the northward migration period.

There is seasonal movement of Pied Oystercatchers from summer breeding areas on exposed ocean beaches into sheltered estuaries and bays during the non-breeding winter period in Tasmania and some parts of Victoria (Weston and Heislers 1995, Taylor *et al*. 2014). The timing of the influx of Pied Oystercatchers into Moreton Bay from January (Fig. 5), after the breeding season, matches the pattern observed in southern Australia. Multiple re-sightings in Moreton Bay of Pied Oystercatchers originally banded as young birds in northern NSW indicate that at least some of the influx likely represents young birds moving north from NSW at the end of the breeding season. The seasonal change in abundance of Red-necked Avocet and Pied Stilt (Fig. 5) is likely due to the movement of birds away from the coast into the interior to breed during the summer wet season (October/November through to March), followed by an influx of birds moving back to the coast from mid-April once the interior dries out during the winter dry season (Alcorn 1990, Close and McCrie 1986, Stuart 2017, Breed *et al*. 2023).

Major river flooding into Moreton Bay is hypothesised to have an immediate negative effect on benthic invertebrate food availability for shorebirds that feed on tidal flats (Clemens *et al*. 2012). Clemens *et al*. (2012) tested whether major flooding of the Brisbane River that started on 11 January and peaked on 13 January 2011 reduced migratory shorebird abundance in areas closest to the flooding by comparing roost counts from throughout Moreton Bay between 1 December 2010 to 13 January 2011 (before flood) and from 3 to 28 February 2011 (post flood). They found that the total number of shorebirds counted across 25 roosts dropped from 12,919 to 11,088 with a slight increase in the proportion of birds in the south of the Bay, which was relatively less flood affected. The drop in numbers of nearly 2,000 shorebirds immediately after the flood comprised primarily small-bodied shorebirds that Clemens *et al.* (2012) suggested had likely left Moreton Bay post-flood. Despite being the most important roost site in Moreton Bay and directly adjoining the mouth of the Brisbane River most affected by the flood, the Port of Brisbane was excluded from the Clemens *et al*. (2012) analysis because it had not been counted within the period between 1 December 2010 to 13 January 2011 (before flood); the closest count was a count of 5,764 migratory shorebirds on 21 November 2010. Despite the expectation that numbers of shorebirds roosting at the Port of Brisbane should have been similarly reduced immediately after the flood, a count on 6 February 2011 recorded a total of 10,002 migratory shorebirds, with the number of smaller species increasing by 3,588 since the November count. Thus, the apparent drop in numbers of nearly 2,000 migratory shorebirds across 25 roost sites in Moreton Bay immediately after the January 2011 floods could be explained by movement of birds to the Port of Brisbane roosts. A broader reanalysis of the impacts of flooding in 2011, 2013 and 2017 by Fuller *et al*. (2021) concluded that impacts on shorebird abundance from severe flooding are weak and/or of very short duration.

Long term trends in shorebird counts at the Port of Brisbane

The declines in Far Eastern Curlew and Grey Plover appear to have been gradual, whereas the decline in Red-necked Stint has occurred since 2017 (Fig. 6). Both Far Eastern Curlew and Grey Plover have experienced significant population declines (Wilson *et al*. 2011, Rogers *et al*. 2023), although the population of Grey Plover appears to have stabilised since 2012 (Rogers *et al*. 2023). Despite Bar-tailed Godwit and Great Knot experiencing significant population declines within Moreton Bay over the period 1992 to 2008 (Wilson *et al*. 2011), the increase in Bar-tailed Godwit counts at the Port since 2002 appears to have been gradual whereas Great Knot counts increased after 2010 (Fig. 6). A similar increase in Great Knot abundance after 2010 was observed at low tide foraging habitat adjacent to the Port (Lloyd *et al.* 2021). The substantial decrease in counts of Bar-tailed

Godwit in 2022 coincided with generally increased counts of up to 3,010 birds roosting at the nearby Lytton Claypan No. 1 roost site; consequently, the reduced counts at the Port over the most recent shorebird year may be due to birds preferentially roosting at Lytton Claypan No. 1. There is no published evidence that the population of Red-necked Stint using Moreton Bay has declined; while one study reported a significant decline in the population visiting Australia (Clemens *et al.* 2016), another found no significant decline (Studds *et al.* 2016), and a third found a significant increase in the population within Moreton Bay over the period 1996-2008 (Wilson *et al.* 2011). Red-necked Stint commonly uses high-tide roosting habitats as feeding areas at high tide; consequently, the decrease in numbers using the Port may reflect a reduction in the suitability of the reclamation area ponds for Red-necked Stint foraging in recent years, or their use of alternative nearby roost sites such as Luggage Point where they are also able to feed.

Although the counts prior to 2002 must be interpreted with caution given that they appear to have been less comprehensive than counts since the standardised survey approach was implemented from 2002, they do provide some interesting contrasts. Great Knot roosted at the Port in substantially larger numbers during the early 1990s than at any time since then, and while counts of Bar-tailed Godwit roosting at the Port have increased significantly over the period 2002-2022, they may have decreased over the period 1991-2001 (Fig. 6). Grey-tailed Tattler and Ruddy Turnstone, which roost preferentially on the inside of the outer bund rock wall, appear to have increased in numbers at the Port only after the outer bund rock wall was constructed in 2004. Pacific Golden Plover, Red-necked Stint and Sharp-tailed Sandpiper also appear to have roosted in relatively low numbers at the Port prior to 2002.

Looking to the future

The Brisbane Port Land Use Plan 2020 (LUP) is the primary planning and regulatory instrument for areas identified as Brisbane core port land and is given statutory force under the *Transport Infrastructure Act 1994* and reviewed at least every ten years. The 2020 LUP anticipates that the FPE reclamation area could be managed to enable it to receive dredged material from port operations until at least around 2044. Once the FPE is capped for future port infrastructure, the LUP notes that future options for dredge material disposal (subject to feasibility analyses) could include (1) drying the material in a yet-to-be-designated area on Fisherman Island before removal to a suitable landfill site remote from the Port; (2) disposal of the material offshore, such as near Mud Island; or (3) the development of an additional dredged material placement and handling site as an extension of the current FPE further into the bay. The last option would effectively be an extension of the current model where the reclamation area is extended to beneficially reuse dredge material and eventually provide land for port growth, as well as further shorebird habitat.

The artificial roost, Fisherman Island claypan and Lytton Claypan No. 1 roost sites are currently managed as conservation buffer areas under the 2020 LUP, where management action includes protection of significant ecological values. The monitoring reported here identifies the Fisherman Island claypan and Lytton Claypan No. 1 roost sites as very significant (Table 2), naturally occurring shorebird roost sites that are important to the network of roost sites in central Moreton Bay. Portions of these roost sites also provide foraging resources for migratory shorebirds when inundated. These two roost sites, together with the artificial roost, are likely to become increasingly relied upon by migratory shorebirds in future as the availability of roosting habitat in the current FPE reclamation area diminishes. Consequently, Port of Brisbane Pty Ltd has and continues to commit substantial resources to enhancing the management of these important roost sites in the conservation buffer on Port land. This includes ongoing management of the permanent roost to ensure the habitat remains suitable for shorebirds, as well as use as an educational facility visited by around 300 school children every year. An important project is currently underway to reduce disturbance and the risk of predation on shorebirds roosting at Lytton Claypan No. 1 by improving fencing, controlling public access, eliminating unauthorised vehicle access, building a walking track and bird hide around the perimeter of the roost to provide educational opportunities, and controlling Red Foxes *Vulpes vulpes*, which have become prevalent in the area.

The proximity of alternative roosts to the Port means that temporal variability and trends in the numbers of shorebirds roosting at the Port cannot be fully understood without considering the potential movement of shorebirds between the Port and these alternative roost sites. A better understanding of these linkages, and potential constraints to the movement of shorebirds between roosts, for example temporal variation in roost suitability due to tide cycles and disturbance, will be important for predicting the impacts on shorebirds of the eventual loss of the Port's current FPE reclamation area for roosting once the area becomes fully reclaimed. Satellite tracking has the potential to provide detailed information on the movements of birds between roost sites and associated foraging areas to better understand these local dynamics (e.g. Lilleyman *et al*. 2020).

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